Short Communication

Surface electromyography and force production of a novel strength training method suitable for microgravity

James Fisher, James Steele, David Jessop

Objectives: Current protocols for resistance training in space flight are hindered by size, mass, noise, vibration and cost, and potentially still lack efficacy. The purpose of the present study was to examine the muscle activation and force output for contralateral limb resisted training compared to traditional resistance training with a view towards the practicality of use in microgravity environments.

Design: Following ethical approval, employing a within-subject design 12 healthy, resistance-trained males performed a 1-repetition maximum bench press (BP) and three isometric tests at differing elbow joint angles (ISO45˚, ISO90˚, ISO135˚) using a Micro-Gym device.

Methods: Surface electromyography (sEMG) was used to assess peak amplitude of the pectoralis major (PM), anterior deltoid (AD) and triceps brachii (TB) muscles. Peak force output for each condition was also measured.

Results: Significant effects by condition were found with planned comparisons revealing statistically significant differences for peak sEMG amplitude for TB in addition to peak force between BP and ISO45, ISO90, and ISO135 ($p < 0.05$). Analyses revealed similar peak sEMG amplitude for PM and AD for BP and isometric conditions ($p > 0.05$).

Conclusions: The present study suggests that a contralateral limb resisted training method could be an efficacious method of recruiting motor units and thus may catalyse muscle fibre adaptations in strength and hypertrophy. This novel method might have considerable application to coaches or trainers not wishing to transport large and heavy equipment or in microgravity environments.

(*Journal of Trainology* 2016;5:46-52)

Key words: resistance training ■ space flight ■ free weight

INTRODUCTION

Increased strength and hypertrophy is evidenced to improve health and wellbeing and increase longevity.[1,2] However, in a weightless environment such as that experienced during space flight, mechanical loading presents a considerable challenge and as such persons are prone to experience significant decreases in strength and muscle mass as well as bone mineral density (BMD) and cardiovascular function.[3,4] Since resistance training (RT) is evidenced to increase each of these physiological parameters,[5,6,7,8] it has been applied as a method of reducing the negative effects of microgravity on human physiology.

However, a recent review of current methods highlight limitations in the physical size and mass, as well as the considerable noise and vibration of the equipment used to maintain the desired level of physiological function.[9,10] In addition the hugely technical elements involved in pieces such as the Dynamic Exercise Countermeasure Device (DCED), Flywheel exercise Device (FWED), Combined Operational Load Bearing External Resistance Treadmill (COLBERT), interim Resistance Exercise Device (iRED), and Advanced Resistance Exercise Device (ARED) present further potential problems should the equipment malfunction. Finally, it has recently been suggested that the above pieces have been ineffective in reducing muscle atrophy and bone loss to the necessary degree and for the time-scale required for a Mars free-return mission in 2018.[11]

It seems apparent that the equipment design and primary intention has always been to target mechanical loading which in turn is aimed to stimulate muscular tension. However, the size principle suggests that as smaller, lower threshold motor units (MU) fatigue, so larger, higher threshold MU are recruited.[12] This size principle, along with more recent reviews of RT for strength[5] and hypertrophy[6] suggest that training to momentary failure (MF) recruits all available muscle fibres, thus catalysing desirable adaptations. As such it is not necessarily external mechanical loading, but rather muscular recruitment tension which is necessary to stimulate the intracellular pathways that lead to increased muscular strength and hypertrophy. This in turn is supported by evidence that equivocally the same improvements in strength and hypertrophy are attainable with both high- and low-load RT strategies.[5,6,13,14] And in addition that maximal co-contraction can be an alternative to external load to catalyse significant improvements in muscle activation, muscular strength and muscle hypertrophy.[15] Furthermore research has shown similar increases in both muscle thickness, following no load and high load (70% 1-repetition maximum) RT,[16] and muscle function following manual partner assisted RT.[17] With this in mind we suggest that provision of resistance through use of a contralateral limb may be another alternative

Received July 27, 2016; accepted September 30, 2016
From the Southampton Solent University, East Park Terrace, Southampton, UK (J.F., J.S., D.J.), and Guided Knowledge, Fareham Innovation Centre, Merlin House, Lee-on-the-Solent, UK (D.J.)
Communicated by Takashi Abe, PhD
Correspondence to James Fisher, Southampton Solent University, East Park Terrace, Southampton, UK. Email: James.Fisher@solent.ac.uk
Journal of Trainology **2016;5:46-52** **http://trainology.org/**

method to producing muscular tension, aiming to improve muscular strength and hypertrophy in microgravity or limited space environments, without the aforementioned challenges and limitations.

Resistance provided by the contralateral limb has previously been described as *"infi-metric"* training. However, since 'infi-metric' appears to be a commercial term used by Jones[17] and Nautilus we have chosen to use 'contralateral limb resisted' or simply 'isometric' where appropriate. Whilst the origins are unknown, Jones[18] discussed this principle and applied it to multiple pieces of Nautilus exercise equipment during the 1970s. However, fundamentally this method does not require any external load and in the present example uses minimal, basic equipment. An example of application would be that, with the hands pressing towards each other in front of the chest (e.g. Figures 2 and 3), as force from the right side of the body exceeds the force of the left side of the body there is either (a). Resulting movement through a full range of motion towards the left side of the body, or (b). An increase in torque production from the left side to prevent movement; resulting in an isometric contraction. As such, when performing an isometric contraction using the contralateral limb, mechanical tension and thus recruitment can be maximal even as the resulting force decreases due to fatigue. In addition any dynamic contractions are near maximal as torque from one side of the body is reduced only sufficiently to allow an eccentric muscle action whilst the contralateral muscles provide sufficient torque to perform a concentric muscle action. Theoretically, this not only represents an efficacious method of training but since muscle groups on opposite sides of the body should fatigue to similar degrees at similar rates, and in addition since this training method is not limited to a minimum force necessary to overcome an external load, this might represent the most logical and efficient form of RT possible. Since any preliminary testing should consider acute responses the present research has compared surface electromyography (sEMG) and force production between a traditional modality of resistance training (e.g. free-weight bench press) and an isometric component of contralateral limb resisted exercise for the pectoral and deltoid muscles under maximal conditions.

METHODS

Research Design

A repeated measures randomised crossover design was adopted to examine the acute effects of two different resistance training modes (free weight bench press 1RM and maximal isometric contractions) for peak sEMG amplitude and peak force production. The study was approved by the Centre of Health, Exercise and Sport Science Research Ethics Committee meeting the ethical standards of the Helsinki declaration and was conducted within the Sport Science Laboratories at the first authors' institution.

Participants

Sample size was considered a priori based upon suggestions from Bates et al.[19] regarding statistical power in biomechanical research. This suggested that 10 participants performing 1 trial per condition would be sufficient to meet the required power of 0.8 at an alpha value of $p \leq 0.05$ for the statistical analyses used. Though 5 trials per condition are suggested we determined that this may result in significant fatigue between trials and conditions and that the simulated power at this sample size and trial number was acceptable.

Twelve healthy male adults (age +18 years) with at least 2 years prior resistance training experience including experience performing free-weight bench press exercise were recruited. They were required to have no medical condition for which RT is contraindicated to participate. All participants completed informed consent documentation prior to any assessments. Demographic characteristics are presented in table 1.

Table 1 Participant demographics

Characteristic	Mean ± Standard Deviation
Age (years)	24 ± 5
Mass (kg)	79.28 ± 7.75
Stature (cm)	179.87 ± 4.69
Training experience (years)	7 ± 5
Bench Press 1RM (kg)	99.58 ± 16.68

Equipment

Stature was measured using a stadiometer (Holtain ltd, Crymych, Dyfed, Wales) and body mass measured using digital scales (Life Measurement Inc, Concord, California, USA). Electromyography (sEMG) was used to measure muscle activation using a Trigno Digital Wireless sEMG System (Delsys,USA). Force data was obtained for the isometric condition using two force transducers (Kistler Quartz Force Links, model number 9321B, Kistler, Amhurst, NY, USA) embedded within the Micro-Gym device (Figure 1; Micro-Gym Pro, Cheshire, UK). For the bench press condition a tri-axial accelerometer (Kistler Piezo BEAM accelerometer, model number 8692C50M1, Kistler, Amhurst, NY, USA) was attached to the barbell.

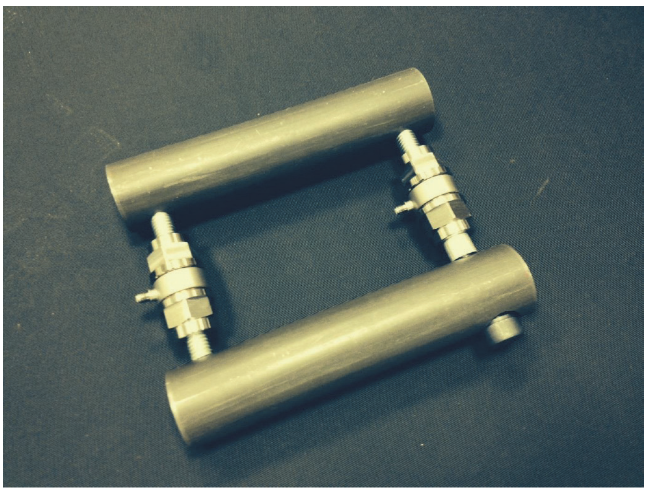

Figure 1 Image of adapted Micro-Gym Pro including force transducers

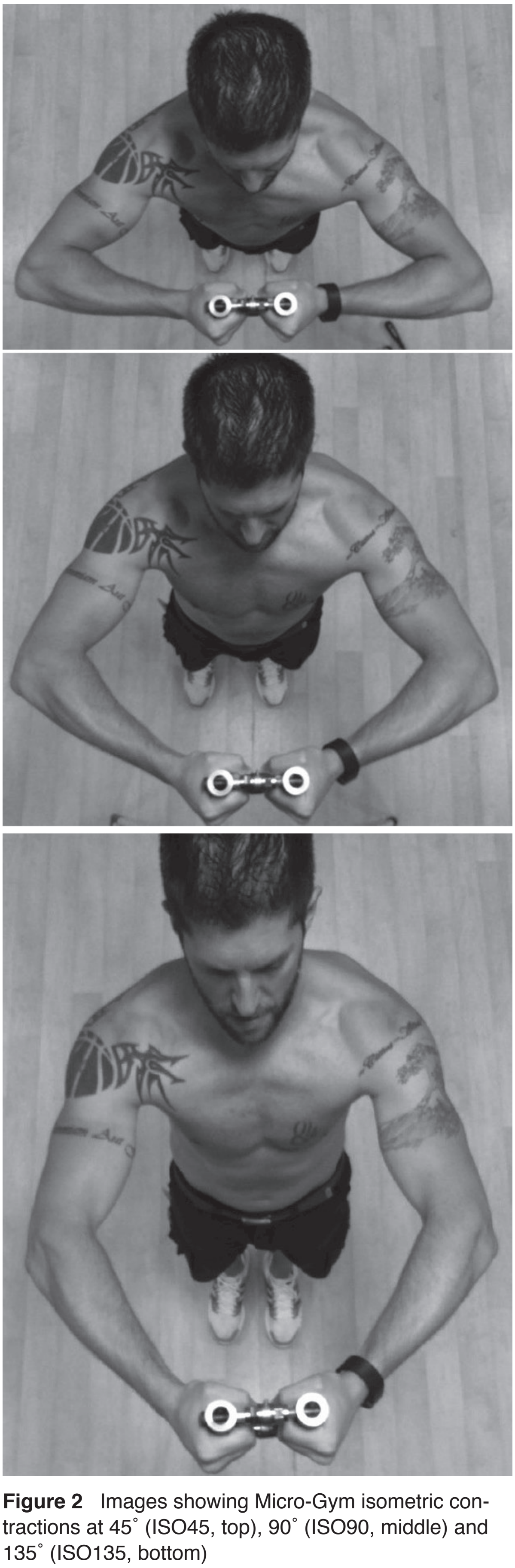

Figure 2 Images showing Micro-Gym isometric contractions at 45˚ (ISO45, top), 90˚ (ISO90, middle) and 135˚ (ISO135, bottom)

Testing

Four different testing conditions were examined; a free-weight bench press 1RM (BP), and maximal isometric contractions using the Micro-Gym device at elbow flexion angles measured at the epicondyle of the humerus using a goniometer [Prestige Medical, Manchester, UK] of 45˚ (ISO45), 90˚ (ISO90), and 135˚ (ISO135). Figure 2 shows images of these actions in a transverse plane. These positions were deemed appropriate since they represent different angular positions between the torso and the humerus; similar to those during a bench press exercise. Joint angles were maintained by use of a researcher holding a goniometer to ensure participants did not deviate from the desired joint angle. A free weight bench press 1RM (BP1RM) was used because it represents a traditional and ecologically valid approach to RT.

Participants attended the laboratory for a single visit where they were counterbalanced to perform either BP or ISO contractions first, with a 30 minute rest between conditions. Before each condition all participants completed a 5 minute warm-up on an arc-trainer (Total Body Arc Trainer, Cybex, MA. USA) up to ~65% age-predicted max heart rate (APMHR). This was followed by specific warm-ups; for the bench press participants performed 8 repetitions at 50%, and then 3 repetitions at 70% of their predicted 1-repetition maximum. Each subject was then given 3-5 attempts to perform a maximal lift with approximately 3 min rest in between to allow for adequate recovery.[20] For the isometric trials (ISO45, ISO90, and ISO135) participants adopted a grip on either side of the Micro-Gym device with shoulders flexed at a 90˚ (see Figure 3). Participants performed an exercise specific warm-up of a practice test at around 50% maximal voluntary contraction at elbow angles of 45˚, 90˚, and 135˚ whereby they were instructed to gradually build to ~50% of their perceived maximal effort over a period of 3 seconds and to hold this effort for

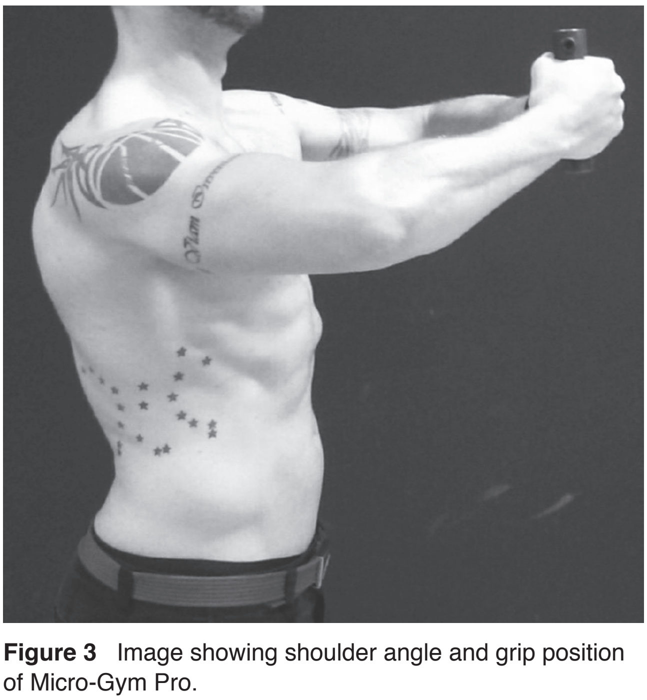

Figure 3 Image showing shoulder angle and grip position of Micro-Gym Pro.

a further 3 seconds. After this participants were instructed to complete the conditions in the same manner; gradually building up to maximal effort over 3 seconds, providing maximal effort for 3 seconds, and then gradually relaxing over a further 3 seconds. For parity to the bench press 1RM, participants were permitted 3 min rest between tested angles with the Micro-Gym. As both contralateral limbs were producing a maximal voluntary contraction the resulting test was isometric in nature and similar to other isometric testing protocols used for lower back[21] and knee[22].

Surface Electromyography

sEMG was measured during each trial for the long head of the triceps brachii (TB), anterior deltoid (AD) and pectoralis major (PM) on the left side of each participant. Electrode placements were followed using recommendations from the Surface Electromyography for the Non-invasive Assessment of Muscles (SENIAM) project[23]. The PM is not listed on SENIAM and so for this muscle electrodes were placed along the mid clavicular line at the level of the 2nd intercostal space. Raw signals were collected at 2000 Hz and were root mean square (RMS) rectified. Peak of the RMS amplitudes for each trial were compared between conditions. Participants were blinded to the sEMG and force output throughout the testing process.

Force Data

For the BP condition acceleration data were taken using the tri-axial accelerometer attached to the barbell, also sampling at 1000 Hz for 10 s. Raw data were filtered at 12 Hz and resolved. The peak was then taken ignoring any spurious peaks which were assumed to occur due to the bar contacting supporting framework. Net force was calculated from the acceleration data using the Pythagorean Theorem (e.g. the square root of the summed squares of the accelerations of each of the three axis) and combining this with the known mass of the barbell during the trial.

For the isometric conditions (ISO45, ISO90, and ISO135) force data were taken using the two force transducers sampling at 1000 Hz for 10 s. The raw data were filtered using a Butterworth filter with cut-off frequency set at 1.4 Hz based on 99% of the frequency content lying under this figure, as recommended by Stergiou[23]. The data from both transducers were then summed and the peak taken.

Statistical Analysis

The independent variable in this study was the trial condition (BP, ISO45, ISO90, and ISO135) and the dependent variables peak RMS amplitude and peak force. Dependent variables tested for normality of distribution using a Kolmogorov-Smirnov test. Data meeting assumptions of normality were then examined using repeated measures analysis of variance (ANOVA) for the factor 'condition'. When assumptions of sphericity were violated when examined using Mauchly's test a Greenhouse-Geisser correction was used. Where significant effects by condition were found using repeated measures ANOVA planned within-subject simple contrasts were performed with the BP condition. Statistical analysis was performed using IBM SPSS Statistics for Windows (version 20; IBM Corp., Portsmouth, Hampshire, UK) and $p \leq 0.05$ set as the limit for statistical significance. Further, 95% confidence intervals (CI) were calculated in addition to ES using Cohen's d[25] for comparison between the BP condition and the isometric conditions for peak RMS amplitude and peak force values to compare the magnitude of difference between groups where an ES of 0.20-0.49 was considered as small, 0.50-0.79 as moderate and ≥ 0.80 as large.[25]

RESULTS

Peak RMS Amplitude

Repeated measures ANOVA revealed a significant effect by condition for the TB ($F_{(3, 33)} = 12.429$, $p < 0.0001$) and the PM ($F_{(3, 33)} = 4.310$, $p = 0.011$). There was no significant effect by condition for the AD ($F_{(1.694, 18.634)} = 1.723$, $p = 0.208$). Planned contrasts revealed significant differences for the TB between BP and ISO45 ($p = 0.005$), ISO90 ($p = 0.001$), and ISO135 ($p < 0.0001$) and for the PM between BP and ISO135 ($p = 0.017$). Figure 4 presents the peak RMS amplitudes for each condition for TB, AD and PM respectively. ESs and 95%CIs for com-

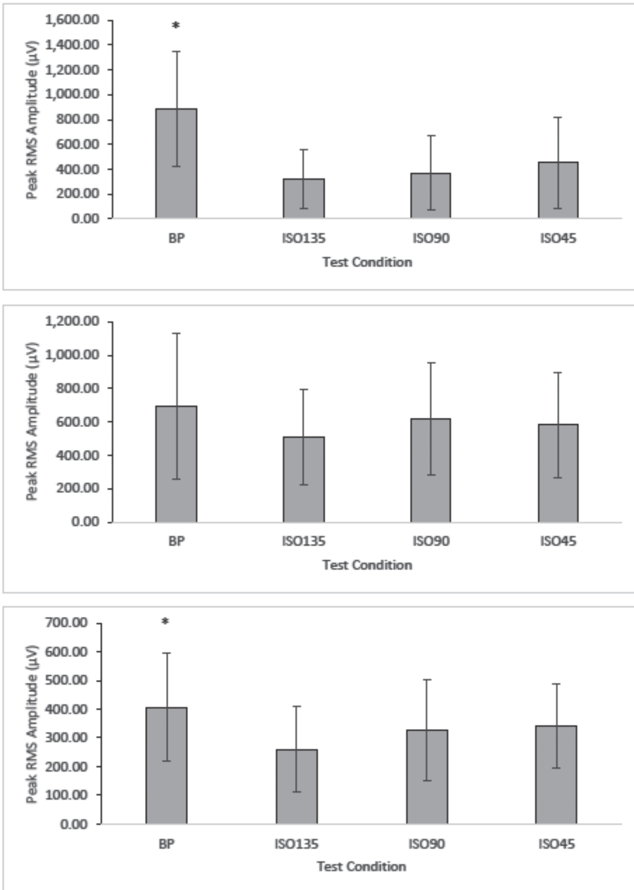

Figure 4 Peak RMS amplitudes for the triceps; * denotes significant difference between BP and ISO135, ISO90, and ISO45 (TOP). Peak RMS amplitudes for the anterior deltoid (MIDDLE). Peak RMS amplitudes for the pectoralis major; * denotes significant difference between BP and ISO135. (BOTTOM).

Table 2 ESs and 95%CIs comparing sEMG differences between BP and isometric conditions

	BP vs ISO135		BP vs ISO90		BP vs ISO45	
Muscle	ES (Cohen's *d*)	95%CIs (μV)	ES (Cohen's *d*)	95%CIs (μV)	ES (Cohen's *d*)	95%CIs (μV)
Tricep	1.51	38.64 to 821.69	0.53	131.11 to 890.27	1.02	216.53 to 900.61
Deltoid	0.60	-282.09 to 506.26	1.07	-155.15 to 303.8	0.26	-101.72 to 474.35
Pectoralis Major	0.81	-58.73 to 191.40	-0.17	-38.01 to 196.85	0.49	-21.22 to 314.27

parisons between BP1RM and the isometric conditions eliciting the highest peak RMS amplitude are reported in table 2.

Force

Repeated measures ANOVA revealed a significant effect by condition for the peak force ($F_{(1.480,\ 16.284)} = 301.413$, $p < 0.0001$). Planned contrasts revealed significant differences for the peak force between BP and ISO45 ($p < 0.0001$), ISO90 ($p < 0.0001$), and ISO135 ($p < 0.0001$). Figure 5 presents peak force for each condition. ESs and 95%CIs for comparisons between BP and the isometric condition eliciting the highest peak force were 4.43 and 568.30N to 868.59N respectively.

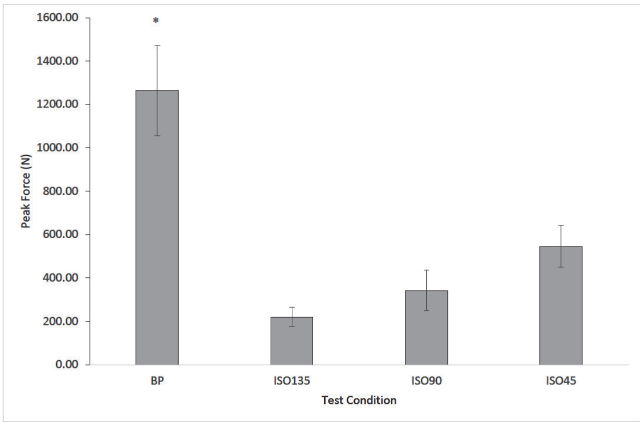

Figure 5 Peak force comparison; * denotes significant difference between BP and ISO135, ISO90, and ISO45.

DISCUSSION

The present study adds to the literature supporting the efficacy of isometric RT for the upper-body.[15,26,27] However, this is the first study to investigate contralateral limb resisted training; a novel approach of resistance aiming to enhance muscular strength and hypertrophy without the need for external loading or complex equipment.

The study produced several important findings; firstly that our data supports the present body of research suggesting that when effort is controlled muscles do not identify their resistance type; they either contract upon instruction or not[5]. sEMG data from the present study showed no significant differences in peak RMS amplitude for AD across all testing modalities suggesting that, under maximal effort conditions, ISO45, ISO90 and ISO135 may have produced similar MU recruitment as the BP condition. Though it should be noted that sEMG amplitudes do not necessarily indicate MU recruitment, particularly under fatiguing contractions[28,29], as all conditions were MVCs it may be appropriate to infer in these conditions that sEMG amplitude likely reflected MU recruitment and thus is comparable between conditions. Furthermore for PM the only statistically significant difference occurred between BP and ISO135 conditions. Since there were no statistically significant differences between BP, ISO90 and ISO45 it seems likely that the increased elbow extension at a 135° angle concurrently decreases the angle of horizontal flexion at the humerus and torso, shortening the PM and reducing the peak RMS amplitude recorded. As such any training protocol for the PM using a contralateral limb resisted approach should maintain an elbow angle of <135° to ensure active insufficiency does not occur (e.g. shortening the muscle to the extent where it cannot contract effectively[30,31]). In contrast to the AD and PM, the TB showed significantly lower peak RMS amplitude for the ISO testing angles compared to the BP. This is likely a product of the nature of performing elbow extension during the BP where the isometric testing in this body position did not require elbow extension and as such did not sufficiently activate the TB. In the present case the isometric testing position perhaps better replicated the execution of a pec-fly or pec-deck exercise. Indeed, previous research has reported far greater amplitudes for the TB for the chest press compared to pec-deck, whilst reporting similar values for the AD and PM between said exercises.[31]

The sEMG data from the present study suggests that contralateral limb resisted training might be an efficacious tool to activate MUs to catalyse increases in strength and hypertrophy through mechanotransduction. Certainly whilst future research needs to confirm this with a proof-of-principle intervention study, the present data supports this hypothesis. Indeed previous research has reported increased sEMG amplitudes, as well as improvements in strength and muscular hypertrophy as a product of muscular tension when performing maximal co-contraction training with inexpensive methodological approaches[15]. In addition the American College of Sports Medicine currently suggest the use of high external resistances (>70% 1RM) or maximal voluntary contractions (MVC) to maximize strength and hypertrophy[33]. Appropriate use of contralateral limb resisted training should incur MVCs to target muscles and meet the suggestions of the ACSM in environments where traditional methods are not suitable (e.g. microgravity) and where space is limited. As such it might serve to eliminate the need for expensive and/or complicated resistance equipment.

The present testing method could be replicated as a training protocol with appropriate manipulation of contraction time, repetitions, and sets of exercise. In addition, the nature of the Micro-Gym apparatus permits multiple exercises to be performed to target specific muscle groups. Previous researchers[5,6,34] have argued that muscular adaptations as a consequence of RT are a result of recruiting as many MUs as possible and achieving high firing rates for a sufficient length of time. As such future research considering an intervention study should manipulate said variables accordingly to attempt to optimise physiological adaptations with this type of training.

The present study also compared force data for the BP and ISO testing angles where analysis revealed significantly higher force output for the BP exercise. We might consider that force output in this case is a product of all mechanical tension resulting from muscle activation. As such, it seems likely that the difference between BP and isometric testing angles are partly a result of the additional muscular contributions from the TB during the BP. At present there appears no research which has compared force production between chest press and pec-deck (or similar) exercises, and as such we have no other data for comparison. This might, in turn, suggest benefits to performing multi-joint, compound exercises compared to single-joint, isolation exercises, which could be considered using contralateral limb resisted training.

Finally, we should acknowledge that this study is not without its limitations. Whilst the testing methods represented ecologically valid approaches, the bench press 1RM considered a concentric muscle action in contrast to the isometric testing using the Micro-Gym. Furthermore, we considered the peak values between these approaches and used previously validated methods of testing. However, as a consequence the sEMG data was not normalised to contraction length between bench press and isometric conditions. In the present study we believe these methods are appropriate but future research should consider parity in contraction type and contraction length when comparing traditional and contralateral limb resisted training. Furthermore, whilst we confirm the familiarity of participants with the bench press exercise, it is possible that they were not familiar with the ISO testing performed. Practice tests were included within our protocol to attempt to reduce learning effect and improve reliability, however differences in familiarity might still have existed.

CONCLUSION

The results of this study indicate that sEMG amplitudes of the AD and PM during the bench press exercise is similar to that of an isometric, contralateral limb resisted, MVC exercise using the Micro-Gym. However, due to the differing nature of the exercises analysed, results revealed greater sEMG amplitudes of the TB when performing the bench press exercise. This increased sEMG amplitude likely resulted in increased force output for the bench press compared to the isometric testing protocols examined herein, although future research should consider this in greater detail. Our knowledge of the size principle along with previous research considering simplified, inexpensive training protocols suggest that contralateral limb resisted training might be an efficacious alternative to more traditional methods and in the case of a micro-gravity environment; might be far more practical. Further research should examine this training approach in greater detail, and coaches should consider this approach to training where transport of large and heavy training equipment is currently used and might be unnecessary.

ACKNOWLEDGEMENTS

The authors have no acknowledgements or research interests to declare.

REFERENCES

1. Srikanthan, P, Karlamangla, AS. Muscle Mass Index As a predictor of longevity in older adults. *Am J Med* 2014; 127: 547-553.
2. Westcott, WL. Resistance Training is Medicine: Effects of Strength Training on Health. *Curr Sports Med Rep* 2012; 11: 209-216.
3. Narici, MV, de Boer, MD. Disuse of the musculo-skeletal system in space and on earth. *Eur J Appl Physiol* 2011; 111: 403-420.
4. Stein, TP. Weight, muscle and bone loss during space flight: another perspective. *Eur J Appl Physiol* 2013; 113: 2171-2181.
5. Fisher, J, Steele, J, Bruce-Low, S, Smith, D. Evidence-Based Resistance Training Recommendations. *Med Sport* 2011; 15: 147-162.
6. Fisher, J, Steele, J, Smith, D. Evidence-Based Resistance Training Recommendations for Muscular Hypertrophy. *Med Sport* 2013; 17: 217-235.
7. Nelson, ME, Fiatarone, M, Morganti, C, et al. Effects of high-intensity strength training on multiple risk factors for osteoporotic fractures. *J Am Med Assoc* 1994; 272: 1909-1914.
8. Steele, J, Fisher, J, McGuff, D, et al. Resistance Training to Momentary Muscular Failure Improves Cardiovascular Fitness in Humans: A review of Acute Physiological Responses and Chronic Physiological Adaptations. *J Exerc Physiol* 2012; 15: 53-80.
9. Carpinelli, RN. Exercise countermeasure to weightlessness during manned spaceflight. *Med Sport* 2014; 18: 42-44.
10. Cotter, JA, Alvin, YU, Haddad, F, et al. Concurrent Exercise on a Gravity-Independent Device during Simulated Microgravity. *Med Sci Sports Exerc* 2015; 47: 990-1000.
11. Loenneke, JP, Wilson, JM, Bemben, MG. Potential exercise countermeasures to attenuate skeletal muscle deterioration in space. *J Trainol* 2012; 1: 1-5.
12. Carpinelli, RN. The size principle and a critical analysis of the unsubstantiated heavier-is-better recommendation for resistance training. *J Exerc Sci Fit* 2008; 6: 67-86.
13. Morton, RW, Oikawa, SY, Wavell, CG, et al. Neither load nor systemic hormones determine resistance training-mediated hypertrophy or strength gains in resistance-trained young men. *J Appl Physiol* 2016. E-Pub ahead of print. Doi: doi:10.1152/japplphysiol.00154.2016
14. Schoenfeld, BJ, Wilson, JM, Lowery, RP, et al. Muscular adaptations in low- versus high-load resistance training: A meta-analysis. *European J Sport Sci* 2014; 20: 1-10.
15. Maeo, S, Yoshitake, Y, Takai, Y, et al. Neuromuscular adaptations following 12-week maximal voluntary co-contraction training. *Eur J Appl Physiol* 2014; 114: 663-673.
16. Counts, BR, Buckner, SL, Dankel, SJ, et al. The acute and chronic effects of “NO LOAD” resistance training. *Physiol Behav* 2016; 164(Pt A): 345-352.
17. Behringer, M, Schuren, T, McCourt, M, et al. Efficacy of manual versus free-weight training to improve maximal strength and performance for microgravity conditions. *J Sport Sci* 2016; 34: 630-636.
18. Jones A. The future of Exercise…an opinion. Nautilus Athletic Journals 1975; http://www.arthurjonesexercise.com/Athletic/ExerciseFuture.PDF. Accessed 7 April 2015.
19. Bates, BT, Dufek JS, Davis HP. The effect of trial size on statistical power. *Med Sci Sports Exerc* 1992; 24: 1059-1068.
20. Brown, LE, Weir, JP. ASEP procedures recommendation I: accurate assessment of muscular strength and power. *J Exerc Physiol* 2001; 4: 1-21.
21. Fisher, J, Bruce-Low, S, Smith, D. A Randomized trial to consider the effect of Romanian deadlift exercise on the development of lumbar

extension strength. *Phys Ther Sport* 2013; 14: 139-145.
22. Fisher, J, Langford, C. The effects of load and effort-matched concentric and eccentric knee extension training in recreational females. *Hum Move* 2014; 15: 147-151.
23. SENIAM Project 92005 Recommendations for sensor locations on individual muscles. http://seniam.org/sensor_location.htm
24. Stergiou, N. Innovative Analysis of Human Movement. Champaign, IL: Human Kinetics, 2004
25. Cohen, J. A power primer. *Psychol Bull* 1992; 112: 155-159.
26. Jones DA, Rutherford OM. Human muscle strength training: the effects of three different regimes and the nature of the resultant changes. *J Physiol* 1987; 391: 1-11.
27. Davies J, Parker DF, Rutherford OM, et al. Changes in strength and cross sectional area of the elbow flexors as a result of isometric strength training. *Eur J Appl Physiol* 1988; 57: 667-70.
28. Enoka, RM, and Duchateau, J. Inappropriate interpretation of surface EMG signals and muscle fiber characteristics impedes progress on understanding the control of neuromuscular function. *J Appl Physiol* 2015; 119: 1516-1518.
29. Vigotsky, A, Beardsley, C, Contreras, B, et al. Greater electromyographic responses for not imply greater motor unit recruitment and 'hypertrophic potential' cannot be inferred. *J Strength Cond Res* 2015 E-Pub ahead of print. Doi: 10.1519/JSC.0000000000001249
30. Lieber, RL, Bodine-Fowler, SC. Skeletal muscle mechanics: Implications for rehabilitation. *Phys Ther* 1993; 73: 844-856.
31. Schoenfeld, BJ. Accentuating muscular development through active insufficient and passive tension. *Strength Cond J* 2002; 24: 20-22.
32. Gentil, P, Oliveira, E, De Araujo Rocha Junior, V, et al. Effects of exercise order on upper-body muscle activation and exercise performance. *J Strength Cond Res* 2007; 21: 1082-1086.
33. Ratamess, NA, Alvar, BA, Evetoch, TK, et al. American College of Sports Medicine position stand. Progression models in resistance training for healthy adults. *Med Sci Sports Exerc* 2009; 41: 687-708.
34. Schoenfeld, BJ, Contreras, B, Willardson, JM, et al. Muscle activation during low-versus high-load resistance training in well-trained men. *Eur J Appl Physiol* 2014; 114: 2491-2497.